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MECHANICAL TESTS ON SPECIMENS FROM LARGE ALUMINUM-ALLOY FORGINGS

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SUMMARY

Results of tensile and bend tests on specimens in the T6 condition from 12- by 12- by 24-inch hand forgings of 7075 (75S) and 2014 (14S) aluminum alloy are presented in this report. Thirty-six notched bend specimens were tested as cantilever beams together with 48 tensile specimens of material adjacent to the bend specimens. Two-thirds of the bend specimens were 1/4 inch wide. In these, the critical extreme fiber stresses were unidirectional. The rest of the bend specimens were 6 inches wide. In these, there were biaxial stress conditions at the critical extreme fiber. The specimens were taken in the axial direction and in both transverse directions. Photogrids were applied to all specimens. The photogrids were photographed at frequent intervals during each test to provide a record of the progress of deformation.

Marked differences were found in the results of tensile tests on specimens in different directions and from different locations in the billet. Corresponding differences were found in the results of the bend tests.

Comparison of the results for the 1/4-inch and 6-inch bend specimens showed that on the average the biaxial stress conditions in the 6-inch specimens caused the strain at failure to be about 0.3 that of the 1/4-inch specimens. For the narrow bend specimens the strain at failure over a 0.1-inch gage length at the root of the notch was found to be from 26 percent less to 150 percent greater than the average strain observed in the region of fracture of adjacent tensile specimens.

It was found that the use of the average tensile strength of material adjacent to the bend specimens as a modulus of rupture in design gave strengths from 33 to 43 percent less for the narrow bend specimens and from 18 to 43 percent less for the wide bend specimens than those obtained in the bend tests. When the average tensile strength in the direction of the bend specimen was used as modulus of rupture the strengths were from 33 to 44 percent less for the narrow specimens and from 17 to 43 percent less for the wide specimens than those obtained in the bend test.

The ratio of modulus of rupture to tensile strength for low-elongation material increased with increase in strain at failure of the bend specimens and with increase in strain at failure of the adjacent tensile specimens.

INTRODUCTION

The present series of tests was intended to give information on low-elongation materials. These tests were suggested by Dr. J. M. Frankland of the Chance-Vought Aircraft Division of United Aircraft Corporation. He pointed out that low-ductility material is particularly notch sensitive; that, except for very mild stress concentrations, fracture starts at a free surface (ref. 1); and that, consequently, biaxial tension usually is the worst condition encountered. The cantilever bend specimens used in these tests had nearly uniaxial tension in the critical extreme fiber for the narrow specimens and had transverse tensile stresses about one-third as great as the axial stress in the elastic range (greater in the plastic range) for the wide specimens. This limited range of biaxiality was expected to be sufficient to give a measure of the performance of low-elongation materials under biaxial stress conditions.

The choice of 2014 and 7075 aluminum-alloy hand forgings for the test specimens was based on their current widespread use; however, it was hoped that the results would be of general value for design with low-elongation materials.

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MATERIAL AND SPECIMENS

One forged billet each of aluminum alloys 7075 and 2014 approximately 12 inches by 12 inches by 24 inches was obtained from the Aluminum Company of America in the F condition and the T41 condition, respectively. (Originally a billet of 2014 was obtained in the T6 condition. It warped excessively and even cracked while being sawed into pieces. Work on this billet was stopped while the second cut was being made.) The sides of the billets were as forged, but the ends had been sawed square. No information was furnished as to how much had been cut from the ends of the billets. Two corners of the 2014-T41 billet were rounded on the end from which the "X" and "Y" specimens were eventually taken. Presumably, very little was cut from that end. The cross sections of the billets were slightly oversized.

The maker's ultrasonic inspection of the 7075-F billet indicated one small defect or discontinuity. Its location was not within any of the specimens. No discontinuity in the 2014-T41 billet was reported by the maker.

The three axes of symmetry were arbitrarily assigned the letters X, Y, and Z, as indicated in figure 1.

Each billet was sawed into 10 pieces. Each piece was approximately 12 inches by 12 inches by not greater than 3 inches thick, in accordance with the maker's recommendation for maximum thickness for heat treatment. The pieces were then heat-treated to the T6 condition by the maker.

The transverse (Y and Z, fig. 1) specimens, usually considered most likely to have the lowest elongation, were from the central portion of the billet. Notched bend and tensile specimens were taken from each piece so that there was a tensile specimen from the location adjacent to each bend specimen. In each tensile specimen the median plane normal to the thickness was at about the same level as the root of the notch of an adjacent bend specimen. All the material in the gage lengths or at the roots of the notches was more than one-tenth the width of the billet from the sides of the billet with the exception of about half the width of the outer longitudinal tensile specimens.

The details of the sampling are indicated in figure 1. Each specimen in the regular sampling was given a 5-symbol designation as follows:

(1) The first symbol indicated the billet.
A indicates 7075-F
C indicates 2014-T41

(2) The second symbol indicated the piece.
2, 3, and 5 as indicated by the numbers in brackets in figure 1.
(Pieces 1, 4, and 6 were set aside for future tests.)

(3) The third symbol indicated the direction of principal stress.
X, Y, and Z as shown in figure 1

(4) The fourth symbol indicated the reference end of the specimen, the end of the slice nearest the notch or center of the gage length, as

shown in figure 1.

M indicates middle
E indicates end
L indicates left
R indicates right
T indicates top
B indicates bottom

(5) The fifth symbol indicated the slice.
Even numbers, 2 to 8, indicate tensile specimens (fig. 1)
Odd numbers indicate bend specimens

The notched bend specimens were made in two widths, 1/4 inch and 6 inches, and had the profile shown in figure 2. They were designed to be tested as cantilever-beam specimens with the large end the reaction end and the notched side in tension. This type of specimen is especially suitable for obtaining a photographic record of the deformation during the test since the region of highest stress is small and does not move much before failure. The depth-width ratios of the beams were 4:1 and 1:6 for the 1/4-inch and 6-inch widths, respectively, on the basis of the uniform depth and 3:1 and 1:8, respectively, on the basis of the depth at the root of the notch. The theoretical extreme fiber stress 0.05 inch either side of the root of the notch, neglecting stress concentration due to the notch, differs from the extreme fiber stress at the root of the notch by less than 1 percent. The notch is a mild stress-raiser. The stress-concentration factor, in the elastic range, at the root of the notch of such a cantilever beam is, according to Neuber (ref. 2), approximately 1.4 referred to the extreme fiber tensile stress for a uniform beam having the dimensions of the net section. This is equivalent to a stress-concentration factor of approximately 2.5 referred to the gross section.

The tensile specimens corresponded to the Federal type-5 tension test specimen with a 2-inch gage length for a sheet thickness of 1/4 inch or less (ref. 3). They were nominally 1/8 inch thick.

A grid of lines spaced nominally 0.250 millimeter (0.01 in.) apart was placed on one face of each of the aforementioned specimens by a photogrid process (ref. 4) using Dyrite emulsion. Check measurements were made on the grids before the specimens were tested.

A tensile specimen and a compressive specimen with cross sections 1/2 inch in diameter were taken in the longitudinal direction and in one of the transverse directions from each billet for determining the stress-strain relations to a strain of about 1 percent. The tensile specimens corresponded to the Federal type-1 tension test specimen (ref. 3). The compressive specimens were $2\frac{1}{4}$ inches long.

PROCEDURE

The tensile tests were made in fluid-support, Bourdon tube, hydraulic testing machines having Tate-Emery load indicators. The Federal type-5 specimens were held in Templin grips and were tested at a "crosshead speed" of about 0.1 inch per minute.

The bend tests were made in one of the machines used for the tensile tests. The principal details of the test fixture can be seen in figure 3 which shows a wide bend specimen ready for testing. The large (reaction) end of the specimen, A, was clamped to a steel block, B, which was bolted to two channels, C, resting on the loading head, D, of the machine. A loading arm, E, was bolted to the other end of the specimen. Loading was accomplished through a ball-ended push rod, F, about $11\frac{1}{2}$ inches long which was engaged in spherical seats, one attached to the weighing head of the machine and the other, in the loading arm at a distance of 20 inches from the root of the notch in the specimen. The narrow bend specimens were tested with the same fixture (fig. 4) with additional blocks for centering and alining the reaction end of the specimen. Guides, G, were provided near the thin end of the specimen and near the push-rod end of the loading arm to eliminate any tendency toward bending of the specimen about the axis of its least moment of inertia. The crosshead speed for the bend tests was over 1 inch per minute. The bend tests on the average took about $1\frac{1}{4}$ times as long for the 2014-T6 specimens and about $1\frac{1}{2}$ times as long for the 7075-T6 specimens as the tensile tests.

Records of the deformation of the specimens during testing were obtained by photographing the grid with a Micro-File Camera, H, figures 3 and 4, attached to the loading head of the machine, in which unperforated 35-millimeter Micro-File panchromatic film was used. The camera was adapted to photograph at natural and at half size. The 2014-T6 tensile specimens were photographed half size. The rest of the specimens were photographed natural size. Illumination was furnished by two 15-watt fluorescent daylight lamps with white enameled reflectors and with their axes 5 inches from the specimen and 2.5 inches either side of the axis of the lens. The specimens were photographed at no load or at a small initial load to obtain a basis for the strain calculations. Photographs were taken at intervals during the first part of the test. Near the end of each test, the camera was operated at its continuous rate of about 67 frames per minute. Each frame number, as soon as it appeared on the counter, was read into the microphone of a tape recorder together with the load readings at frequent intervals.

Measurements on the specimens and on the negatives were made with a comparator having a microscope which magnified 100 diameters and having graduations at intervals corresponding to 0.001 millimeter travel of the stage.

The fractured tensile specimens were examined to determine the location of the minimum local elongation at the fracture. A longitudinal line through this location was selected, along which measurements on the specimen or on the negatives were made. Elongation measurements were made on the fractured tensile specimens from each end of the gage length to the edge of the fracture. The values thus obtained are somewhat lower than values obtained in routine measurement of total distance between gage marks while the two parts of the fracture are pressed together. Strain just before fracture was usually determined from measurements on the negatives. Readings were taken at each intersecting grid line in the vicinity of the fracture and at greater intervals along the rest of the gage length. For some of the 7075-T6 specimens the strain just before fracture was estimated from the residual strain in the fractured specimen, excluding the spaces in which local necking took place.

The bend-specimen photogrid measurements were made either at the edge of the notch or along a line tangent to the root of the notch or parallel to the tangent at a distance of less than 0.01 inch. Determinations of strain just before fracture were made from measurements on negatives. Measurements were also made on several of the fractured 7075-T6 bend specimens.

The tensile and compressive specimens with round cross sections were tested in the testing machine used for most of the other tests. A pair of Tuckerman optical strain gages with a 1-inch gage length was used to measure strain. The stress rate was approximately 2,000 psi/min.

RESULTS

Tensile and Compressive Tests

The results of the tensile and compressive tests in which the specimens were subjected to strain up to 1 percent are given in table I.

The results of the tensile tests of the 7075-T6 and the 2014-T6 photogrid specimens are given in tables II (a) and II (b), respectively.

The 7075-T6 specimens showed marked differences in tensile properties with direction. Also, for specimens in one direction there was often a greater difference between specimens from the same slice than between specimens in the same relative location in slices 6 to 9 inches apart. The "E" group of longitudinal specimens had the highest elongation in 2 inches. The elongation for the "M" group of longitudinal specimens averaged about 0.6 as high as that for the "E" group. The transverse specimens in the Y-direction had the lowest elongations and there was little difference between the two groups. The elongations of the transverse specimens in the Z-direction fell into two groups, the "B" group which had elongations slightly above the poorer longitudinal group and the "T" group which had elongations about the same as those of the transverse specimens in the Y-direction. The differences in tensile strength were not so marked. However, for each direction the average values of tensile strength for the two groups were in the same order as the average elongations.

The differences in tensile properties of the 2014-T6 specimens in the three directions or between groups of specimens according to location were not nearly so marked as the differences in tensile properties of the 7075-T6 specimens. The transverse specimens in the Y-direction had the highest average tensile strength and elongation. They were followed by the longitudinal specimens and by the transverse specimens in the Z-direction in that order.

More than half the tensile specimens broke outside the middle third of the gage length. While this may have affected some of the individual values of elongation in 2 inches there is little likelihood that the group differences discussed previously were affected.

Out of 24 specimens of each material, only 4 of the 7075-T6 specimens and 2 of the 2014-T6 specimens broke within 1/8 inch of the location corresponding to the root of the notch of an adjacent bend specimen. These were all among the more ductile specimens.

The five 7075-T6 specimens which broke at a strain of over 10 percent and the eight 2014-T6 specimens which broke at a strain of over 5 percent in 2 inches were the only ones for which the load became constant or decreased before fracture.

Cracks appeared in some of the tensile specimens (in some of the bend specimens, also) before fracture. Usually these cracks were not associated with the final fracture. A view of specimen A5ZB4 after the fracture is shown in figure 5(a). This specimen broke at a stress of 73,100 psi and at an average strain in 2 inches of over 8 percent. Although several cracks were visible in the photograph taken less than a second before fracture (fig. 5(b)), there was no evidence of cracks along the line where the fracture occurred. There were definite indications of the crack pointed out by the arrow (shown in fig. 5(b)) in a photograph taken about a minute before at a stress of 70,400 psi and a strain of about 5 percent.

Values of strain in 0.01 inch just before fracture are shown in figure 6(a) together with values of residual strain obtained from measurements, after fracture, on the same tensile specimen in the region of the fracture. Further straining in the last fraction of a second before fracture was limited to a very small region.

Values of strain in 0.1 inch for the tensile specimens just before fracture are given in table II for comparison with corresponding values of strain for the bend specimens (table III). The measurements of strain obtained from photographs of the tensile specimens just before fracture showed that for nearly all the specimens, other than those for which the load became constant or decreased before fracture, the maximum strain in 0.1 inch could be obtained within ±0.005 from

$$\text{Maximum strain in 0.1 inch} = \frac{5 \times \text{Strain in 2 inches}}{4} - 0.0025$$

Bend Tests

The results of the tests of the 7075-T6 and the 2014-T6 notched bend specimens are given in table III.

Values of strain in 0.01 inch just before fracture are shown in figure 6(b) together with values of residual strain obtained from measurements, after fracture, on the same narrow bend specimen near the root of the notch. The bend specimen was adjacent to the tensile specimen for which similar data are shown in figure 6(a). Strain accompanying the fracture of the bend specimens was not so localized as that for the tensile specimens.

In general, the values of modulus of rupture and of extreme fiber strain in 0.1 inch just before fracture fell into the same groupings as the corresponding tensile strengths and elongations in 2 inches. For the more ductile groups the values of modulus of rupture for the wide specimens were about the same as those for the narrow specimens. For the less ductile groups the values of modulus of rupture for the wide specimens were much less than for the narrow specimens. The extreme fiber strain in 0.1 inch just before fracture was in each case much smaller for the wide specimen than for the narrow specimens of the same group, the average ratio being about 0.3. The strain in 0.1 inch just before fracture for the narrow specimens varied from 26 percent less to 150 percent more than the corresponding average strain for adjacent tensile specimens.

METHODS OF ANALYSIS

Ratios of modulus of rupture of a bend specimen to the average tensile strength of the adjacent tensile specimens (table III) varied from 1.50 to 1.76 for the narrow specimens of 7075-T6, from 1.46 to 1.73 for the narrow specimens of 2014-T6, from 1.27 to 1.76 for the wide specimens of 7075-T6, and from 1.22 to 1.68 for the wide specimens of 2014-T6.

If the tensile strengths of adjacent specimens are taken as values of modulus of rupture in design, the design strengths would be from 0.57 to 0.68 times the observed values for the narrow specimens and from 0.57 to 0.82 times the observed values for the wide specimens. Similarly, the ratios of average tensile strength in one direction to observed values of modulus of rupture of specimens of the same material in the same direction vary from 0.56 to 0.67 for the narrow specimens and from 0.57 to 0.83 for the wide specimens.

Ratios of modulus of rupture to tensile strength generally increased with the extreme fiber strain in 0.1 inch just before fracture (fig. 7). For the narrow bend specimens the equation $\frac{\text{Modulus of rupture}}{\text{Tensile strength}} = 1.43 + 2.6\epsilon_b$ represents the data within ± 0.05 for values of ϵ_b between 0.02 and 0.08 where ϵ_b is the extreme fiber strain in 0.1 inch in the bend specimen just before fracture. For the more ductile specimens the ratio of modulus of rupture to tensile strength was somewhat lower than that given by the equation; however, for these specimens the ratio was 1.58 or above.

The effect of low ductility is much more marked for the wide bend specimens. For these specimens the equation $\frac{\text{Modulus of rupture}}{\text{Tensile strength}} = 1 + 27.5\epsilon_b$ represents the data within ± 0.16 for values of ϵ_b between 0.008 and 0.022. For the other specimens the ratios were 1.69 or above.

Similar relations hold with regard to the average strain ϵ_t in 2 inches just before fracture in tensile specimens adjacent to the bend specimens (fig. 8). This enables one to estimate modulus of rupture from the tensile data. For all the narrow bend specimens, the modulus of rupture equals $(1.5 \pm 0.1 + 2\epsilon_t)$ times the tensile strength. For the wide bend specimens, with the exception of those with ratios of modulus of rupture to tensile strength above 1.6 and strains of adjacent tensile specimens above 6.5 percent, the modulus of rupture equals $(1 \pm 0.12 + 12.5\epsilon_t)$ times the tensile strength.

DISCUSSION

The behavior, during machining, of the material from which the specimens were made indicates that residual stresses in the specimens were very small or were quite localized. There was very little warping during the machining and the tensile specimens were as straight as, or straighter than, those usually obtained from a flat sheet. The effects of residual stresses were vividly shown by the warping and spontaneous splitting which occurred during the sawing of the 2014-T6 billet upon which work was discontinued during the second cut.

The marked differences in the elongations of specimens in the same direction, but with their test sections originally about 4 inches apart in the billet, show the importance of adequate sampling in obtaining representative mechanical properties in large forgings. While the corresponding differences in tensile strength were not great, because of the relatively low slopes of the stress-strain curves above strains of 1 to $1\frac{1}{2}$ percent, differences in elongation would result in appreciable differences in tensile strength for specimens breaking at lower strains. An explanation of the differences in elongation with direction and with location would require metallographic examinations which are outside the scope of this investigation. However, it seems reasonable to suggest that the directional metallurgical characteristics, both of a forging at points of greatest stress and of the test specimens, should be considered in sampling the material.

A gage length of 0.1 inch was chosen as the basis of the strain and elongation measurements for several reasons. The theoretical extreme fiber stress, neglecting the stress concentration due to the notch, varied by less than 1 percent over a gage length of 0.1 inch symmetrical to the root of the notch in a bend specimen. A gage length of this order enables one to obtain fairly consistent measurements of strain despite local irregularities in the yielding of the material and possible experimental errors. The relation between strain in 0.1 inch and strain in 2 inches, which was found to hold for the less ductile tensile specimens, made possible a comparison of the strain in 0.1 inch just before fracture in the bend specimens with the strain in 2 inches just before fracture in the tensile specimens. The latter may be obtained with an autographic stress-strain recorder operating to fracture.

Comparison of strain just before fracture with residual strain after fracture showed that the straining associated with the fracture was much more localized in the tensile specimens than in the bend specimens. This indicates that the strain just before fracture is the better basis for comparison of the tensile and bend tests.

Stress concentration due to the notch did not seem to affect the results of the bend tests to any great extent. Computations of moment were made for four of the narrow bend specimens on the assumption that the strain gradient was uniform from the strain at the root of the notch to an equal but negative strain at the opposite edge of the section. The stress distribution was in accordance with an "average" stress-strain relation in tension and compression. This was obtained from tensile data for the adjacent specimens by computing the true stresses corresponding to several values of strain and adjusting this stress-strain relation for the difference between the tensile yield strength (offset = 0.2 percent) and the average of the tensile and compressive yield strengths. The experimental values of moment were from 1.7 percent less to 7.7 per cent greater and average 2 percent greater than the calculated values. If the stress-raising effect of the notch had been considered in the calculations, the average difference would have been still greater. However, the effect of even such mild stress-raisers as these would be expected to be serious for material with elongation near zero.

The greatly reduced values of extreme fiber strain in the wide bend specimens just before fracture as compared with the corresponding strains in the nearby narrow specimens may be attributed largely to the biaxial stress conditions in the wide specimens. It is possible that the differences may have been increased by a size effect, as indicated by the notch bend tests reported in reference 5. In those tests a highly biaxial stress pattern was induced by a sharp notch. Bend tests of geometrically similar specimens showed that the final strain decreased as the size of specimen was increased. Data to evaluate the relative effects of biaxiality and of size of specimen were not obtained either in those tests or in the present tests.

The modulus-of-rupture values for wide bend specimens adjacent to tensile specimens which elongated without increase of load or showed significant localized yielding were approximately the same as those for the corresponding narrow bend specimens even though the strains just before fracture were much lower. Apparently, the moment required for the induced transverse stresses was approximately equal to the decrease in moment due to the lower strain before fracture. For the less ductile material, the stress gradients corresponding to the differences in breaking strain were greater so that the net changes in moment would be decreases. This would account for the modulus-of-rupture values for the less ductile specimens being less for the wide than for the narrow specimens.

No definite information as to the behavior of material with elongation near zero was furnished by these tests. The lowest net elongation was 1 percent (1.5-percent standard elongation) and the corresponding strain in 0.1 inch just before fracture was 2.2 percent. The extreme fiber strains in 0.1 inch just before fracture were 2.2 percent and 0.8 percent for the narrow and wide bend specimens, respectively. If the same relationship between the limiting strains of the narrow and wide specimens should hold for material with elongation approaching zero, the ratio of modulus of rupture to tensile strength would be much less than one for specimens of such material in which highly biaxial stress conditions exist.

CONCLUSIONS

Tensile and bend tests on material in the T6 condition which was cut from 12- by 12- by 24-inch hand forgings of 7075 and 2014 aluminum alloy lead to the following conclusions:

(1) The stress and strain at failure varies with the location and the direction of the specimen in the forging, but there is no consistent relation between the values for specimens parallel to the direction of the length of the forging and the values for specimens in either transverse direction. This, together with the variability shown by specimens in the same direction, shows the need for adequate sampling in determining the properties of large forgings.

(2) Biaxial tensile stress conditions, resulting from induced transverse stresses combined with direct bending stresses, cause fracture to occur at a much lower strain than for bend specimens in which the critical stresses are uniaxial. This results in a marked reduction in strength for low-elongation material but not for material which yields appreciably under tensile stress at the maximum load.

(3) The use of the tensile strength of adjacent material for modulus of rupture in design results in conservative values for sound material with little residual stress, if the critical stress pattern is uniaxial or, if biaxial, for material with net elongation of 1 percent or greater.

(4) The ratio of modulus of rupture to tensile strength for low-elongation material increases with increase in strain at the beginning of failure.

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REFERENCES

1. Dana, A. W., Aul, E. L., and Sachs, G.: Tension Properties of Aluminum Alloys in the Presence of Stress-Raisers. I - Effects of Triaxial Stress States on the Fracturing Characteristics of 24S-T Aluminum Alloy. NACA TN 1830, 1949.

2. Neuber, H. (F. A. Raven, trans.): Theory of Notch Stresses: Principles for Exact Stress Calculation. Translation 74, The David W. Taylor Model Basin, U. S. Navy, Nov. 1945. (Kerbspannungslehre: Grundlagen für genaue Spannungsrechnung. Julius Springer (Berlin), 1937.)

3. Anon.: General Specification for Inspection of Metals. Federal Specification QQ-M-151a, Federal Standard Stock Catalog, sec. IV, pt. 5, Nov. 27, 1936.

4. Miller, James A.: Improved Photogrid Techniques for Determination of Strain Over Short Gage Lengths. Proc. Soc. Exp. Stress Analysis, vol. X, no. 1, 1952, pp. 29-34.

5. Shearin, Paul E., Ruark, Arthur E., and Trimble, R. M.: Size Effects in Steels and Other Metals From Slow Notch Bend Tests. Symposium on Fracturing of Metals, A.S.M. (Cleveland), 1948, pp. 167-188.

TABLE I.- RESULTS OF TENSILE AND COMPRESSIVE TESTS TO 1 PERCENT STRAIN ON SPECIMENS FROM ALUMINUM-ALLOY FORGINGS

Test	Direction	Location in billet (between specimens)	Yield strength, ksi (offset, 0.2 percent)	Initial modulus of elasticity, ksi
7075-T6:				
Tensile	Longitudinal	A3XE4 and A3XM4	66.3	10,300
Compressive	Longitudinal	A3XE4 and A3XM4	69.6	10,300
Tensile	Transverse	A2YL6 and A2YR6	63.7	10,200
Compressive	Transverse	A2YL6 and A2YR6	68.0	10,200
2014-T6:				
Tensile	Longitudinal	C3XE4 and C3XM4	58.3	10,600
Compressive	Longitudinal	C3XE4 and C3XM4	59.7	10,600
Tensile	Transverse	C5ZB4 and C5ZT4	57.6	10,600
Compressive	Transverse	C5ZB4 and C5ZT4	60.2	10,600

TABLE II.- RESULTS OF TENSILE TESTS ON SPECIMENS

(a) 7075-T6 forging

Specimen number	Tensile strength, ksi	Net elongation in 2 in., percent (a)	Strain in 0.1 in. just before fracture, percent	Remarks
Longitudinal specimens				
A3XM2	79.5	7.4	10.6	
A3XM4	74.8	7.3	10.5	
A3XM6	75.4	7.2	8.6	Fracture was outside middle third of gage length; fracture was within 1/8 in. of location of root of notch of adjacent bend specimen
A3XM8	80.5	6.9	10.2	Fracture was outside middle third of gage length
Average M	77.6	7.2		
A3XE2	81.7	12.1	----	Fracture was outside middle third of gage length; fracture was within 1/8 in. of location of root of notch of adjacent bend specimen; load became constant or decreased before specimen broke
A3XE4	79.0	13.1	28.2	Fracture was outside middle third of gage length; fracture was within 1/8 in. of location of root of notch of adjacent bend specimen; load became constant or decreased before specimen broke
A3XE6	79.4	11.5	22.4	Fracture was outside middle third of gage length; fracture was within 1/8 in. of location of root of notch of adjacent bend specimen; load became constant or decreased before specimen broke
A3XE8	80.7	10.5	23.9	Fracture was outside middle third of gage length; load became constant or decreased before specimen broke
Average E	80.2	11.8		
Average X	78.9	9.6		
Transverse specimens				
A2YL2	68.3	1.3	1.9	Fracture was outside middle third of gage length
A2YL4	72.1	3.5	4.9	
A2YL6	68.2	1.2	----	Fracture was outside middle third of gage length
A2YL8	68.8	1.4	2.1	
Average L	69.4	1.8		
A2YR2	70.5	2.1	3.3	
A2YR4	72.1	3.6	5.2	
A2YR6	68.9	1.2	----	Fracture was outside middle third of gage length
A2YR8	70.5	1.4	2.9	
Average R	70.5	2.1		
Average Y	69.9	2.0		
A5ZT2	71.9	2.1	2.6	
A5ZT4	73.2	2.1	2.5	
A5ZT6	70.7	3.1	4.4	
A5ZT8	70.3	2.0	4.2	
Average T	71.5	2.3		
A5ZB2	[b]74.3	[b]6.1	----	Fracture was outside middle third of gage length
A5ZB4	73.1	7.5	9.7	
A5ZB6	72.6	9.9	16.7	Load became constant or decreased before specimen broke
A5ZB8	73.4	8.1	8.0	Fracture was outside middle third of gage length
Average B	73.0	8.5		
Average Z	72.3	5.4		

[a]These are minimum values, excluding gap between edges of fracture. They are a little lower than values obtained from routine measurement of total distance between two points originally 2 in. apart. With addition of elastic strain at fracture they would be approximately equal to maximum strain recorded by an autographic recorder.

[b]Test was stopped near end (stress 74.3 ksi) to reload camera. Several false starts were made in resuming test because of imperfect switch connection; fracture occurred soon after final resumption of test at unusually high loading rate; excluded from averages.

TABLE II.- RESULTS OF TENSILE TESTS ON SPECIMENS - Concluded

(b) 2014-T6 forging

Specimen number	Tensile strength, ksi	Net elongation in 2 in., percent (a)	Strain in 0.1 in. just before fracture, percent	Remarks
Longitudinal specimens				
C3XM2	64.5	2.7	4.1	
C3XM4	64.6	3.3	5.2	
C3XM6	64.2	2.9	4.4	Fracture was outside middle third of gage length
C3XM8	65.2	3.8	5.1	
Average M	64.6	3.2		
C3XE2	65.6	2.1	3.7	Fracture was outside middle third of gage length
C3XE4	65.7	5.2	7.4	Fracture was outside middle third of gage length; load became constant or decreased before specimen broke
C3XE6	64.3	2.4	3.5	Fracture was outside middle third of gage length
C3XE8	65.3	1.8	3.3	
Average E	65.2	2.9		
Average X	64.9	3.0		
Transverse specimens				
C2YL2	66.1	5.8	-----	Load became constant or decreased before specimen broke
C2YL4	65.8	3.7	5.5	
C2YL6	65.6	7.3	-----	Load became constant or decreased before specimen broke
C2YL8	67.1	7.3	20.3	Fracture was outside middle third of gage length; fracture was within 1/8 in. of location of root of notch of adjacent bend specimen; load became constant or decreased before specimen broke
Average L	66.2	6.0		
C2YR2	65.8	5.1	7.1	Fracture was outside middle third of gage length; load became constant or decreased before specimen broke
C2YR4	65.2	4.5	6.9	Fracture was outside middle third of gage length; load became constant or decreased before specimen broke
C2YR6	66.4	7.4	15.2	Fracture was outside middle third of gage length; fracture was within 1/8 in. of location of root of notch of adjacent bend specimen; load became constant or decreased before specimen broke
C2YR8	67.1	7.6	20.0	Fracture was outside middle third of gage length; load became constant or decreased before specimen broke
Average R	66.1	6.2		
Average Y	66.1	6.1		
C5ZT2	62.9	1.9	3.3	Fracture was outside middle third of gage length
C5ZT4	61.7	1.4	2.5	Fracture was outside middle third of gage length
C5ZT6	63.6	2.0	3.3	Fracture was outside middle third of gage length
C5ZT8	64.7	1.4	2.3	Fracture was outside middle third of gage length
Average T	63.2	1.7		
C5ZB2	61.1	1.3	2.3	
C5ZB4	61.5	1.0	2.2	Fracture was outside middle third of gage length
C5ZB6	63.3	1.3	2.2	
C5ZB8	64.1	1.3	2.3	
Average B	62.5	1.2		
Average Z	62.9	1.4		

[a]These are minimum values, excluding gap between edges of fracture. They are a little lower than values obtained from routine measurement of total distance between two points originally 2 in. apart. With addition of elastic strain at fracture they would be approximately equal to maximum strain recorded by an autographic recorder.

TABLE III.- RESULTS OF BEND TESTS ON SPECIMENS FROM ALUMINUM-ALLOY FORGINGS

Specimen number	Width, in.	Maximum moment at root of notch, lb-in.	Modulus of rupture, ksi	Ratio of modulus of rupture to average tensile strength of adjacent specimens		Extreme fiber strain in 0.1 in. just before fracture, percent		Ratio of extreme fiber strain to average strain of adjacent tensile specimens	
				Narrow bend specimens	Wide bend specimens	Narrow bend specimens	Wide bend specimens	Narrow bend specimens	Wide bend specimens
7075-T6									
A3XM3	1/4	2,870	121.9	1.58		8.1		0.77	
A3XM5	6	74,400	132.2		1.76		4.8		0.50
A3XM7	1/4	3,080	131.7	1.69		14.6		1.55	
A3XB3	1/4	3,270	139.0	1.73		25.8		[a].91	
A3XB5	6	78,100	138.8		1.75		3.8		.15
A3XB7	1/4	3,210	136.4	1.70		20.7		.89	
A2YL3	1/4	2,730	116.6	1.66		6.9		2.03	
A2YL5	6	58,000	103.1		1.47		1.7		[a].35
A2YL7	1/4	2,520	107.0	1.56		4.9		[a]2.33	
A2YR3	1/4	2,720	116.4	1.65		8.0		1.88	
A2YR5	6	50,200	89.2		1.27		1.0		[a].19
A2YR7	1/4	2,470	104.7	1.50		2.9		[a]1.00	
A5ZM3	1/4	2,580	110.4	1.52		3.6		1.41	
A5ZM5	6	55,000	94.2		1.31		1.7		.49
A5ZM7	1/4	2,570	109.9	1.56		3.5		.81	
A5ZB3	1/4	2,770	117.9	1.61		11.7		[a]1.21	
A5ZB5	6	70,600	125.5		1.72		6.1		.46
A5ZB7	1/4	3,010	128.7	1.76		20.2		1.62	

Specimen number	Width, in.	Maximum moment at root of notch, lb-in.	Modulus of rupture, ksi	Ratio of modulus of rupture to average tensile strength of adjacent specimens		Extreme fiber strain in 0.1 in. just before fracture, percent		Ratio of extreme fiber strain to average strain of adjacent tensile specimens	
				Narrow bend specimens	Wide bend specimens	Narrow bend specimens	Wide bend specimens	Narrow bend specimens	Wide bend specimens
2014-T6									
C3XM3	1/4	2,370	100.8	1.56		4.5		0.97	
C3XM5	6	54,000	95.6		1.48		1.5		0.31
C3XM7	1/4	2,420	102.4	1.58		5.3		1.12	
C3XB3	1/4	2,600	110.1	1.68		13.9		2.50	
C3XB5	6	60,000	106.3		1.64		1.8		.33
C3XB7	1/4	2,380	100.6	1.55		3.8		1.12	
C2YL3	1/4	2,480	105.8	1.60		6.1		[a]1.11	
C2YL5	6	62,480	110.6		1.68		3.1		[a].56
C2YL7	1/4	2,690	114.5	1.73		----		----	
C2YR3	1/4	2,500	106.6	1.65		7.9		1.13	
C2YR5	6	59,800	106.0		1.61		2.2		.20
C2YR7	1/4	2,620	110.5	1.66		13.0		.74	
C5ZM3	1/4	2,200	94.1	1.51		2.7		.93	
C5ZM5	6	50,000	88.4		1.41		1.5		.52
C5ZM7	1/4	2,270	97.0	1.51		----		----	
C5ZB3	1/4	2,200	93.8	1.53		2.2		.98	
C5ZB5	6	43,000	76.1		1.22		.8		.36
C5ZB7	1/4	2,180	93.2	1.46		3.1		1.38	

[a]One adjacent tensile specimen.

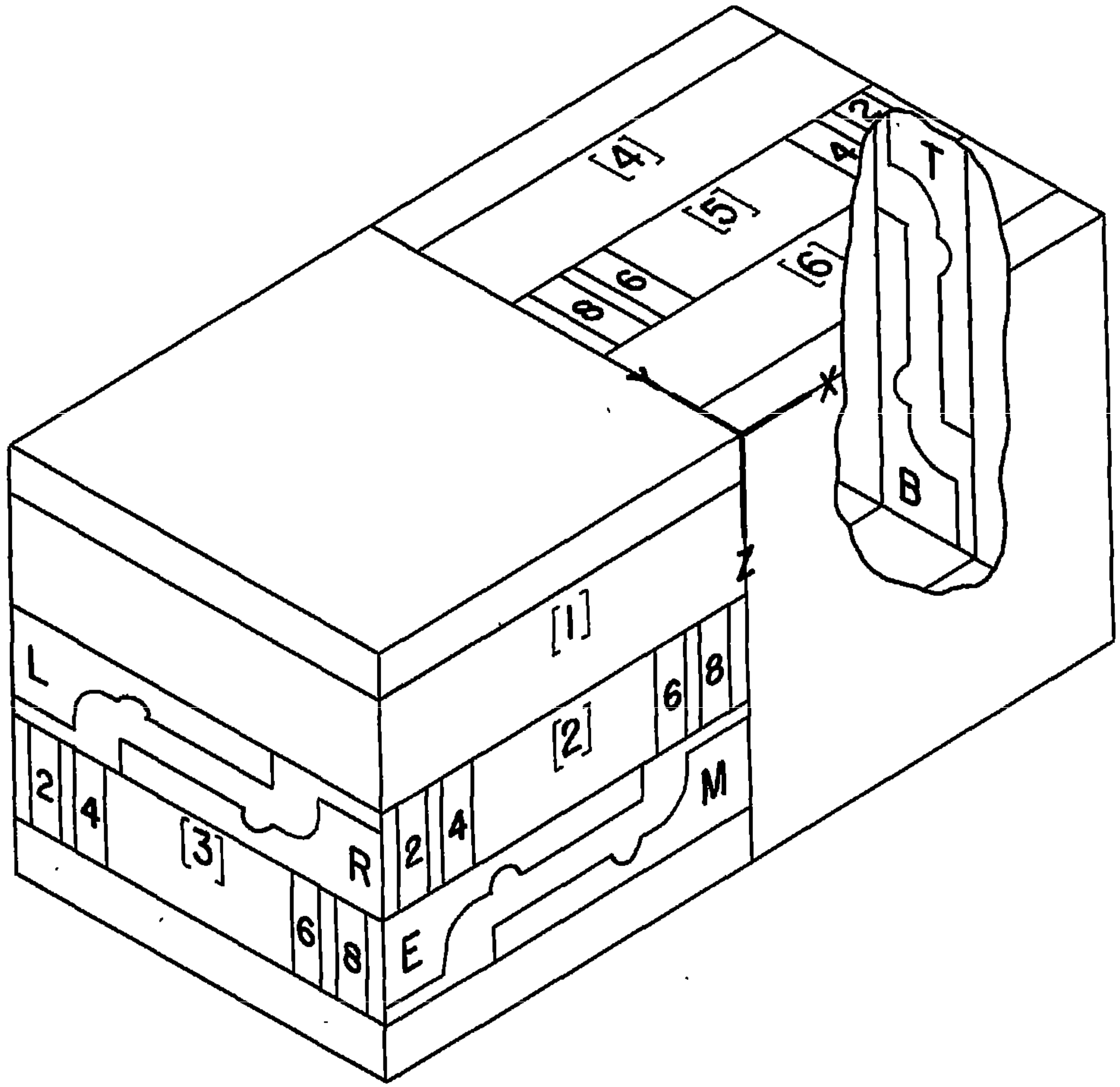


Figure 1.- Locations of specimens in forging.

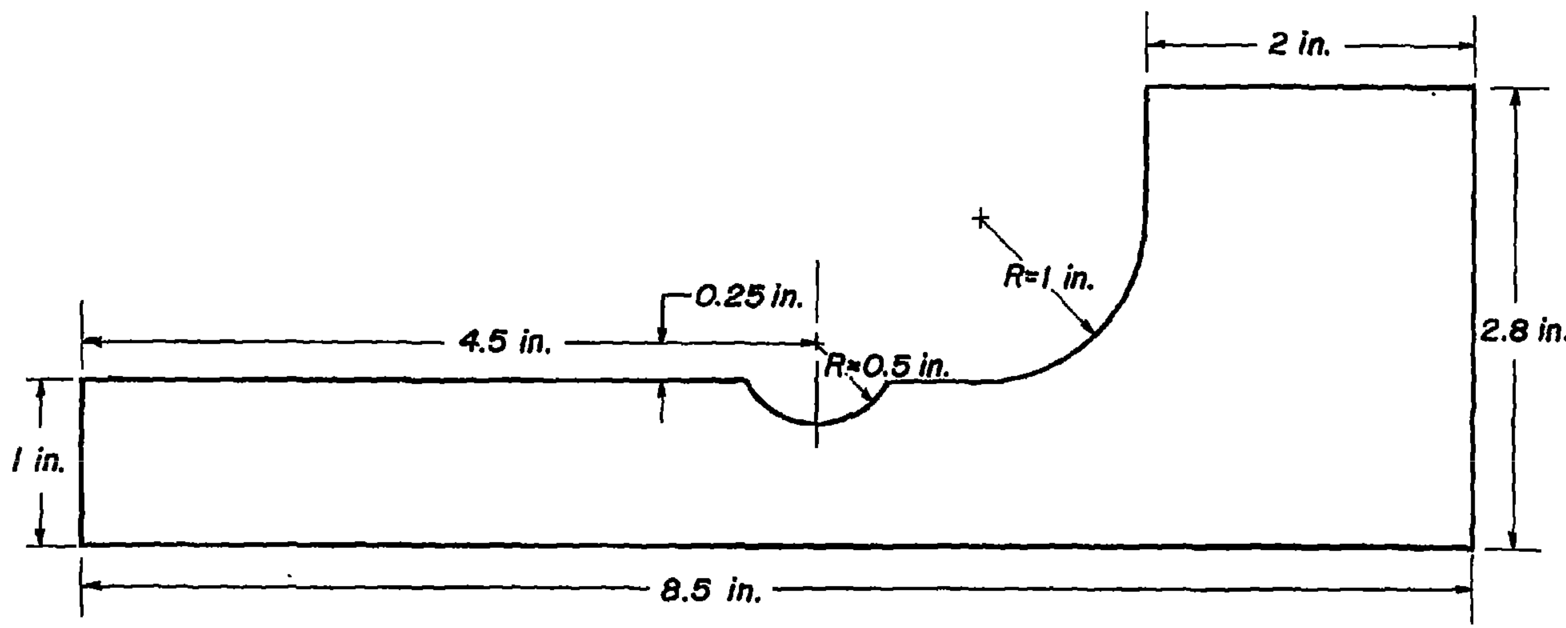
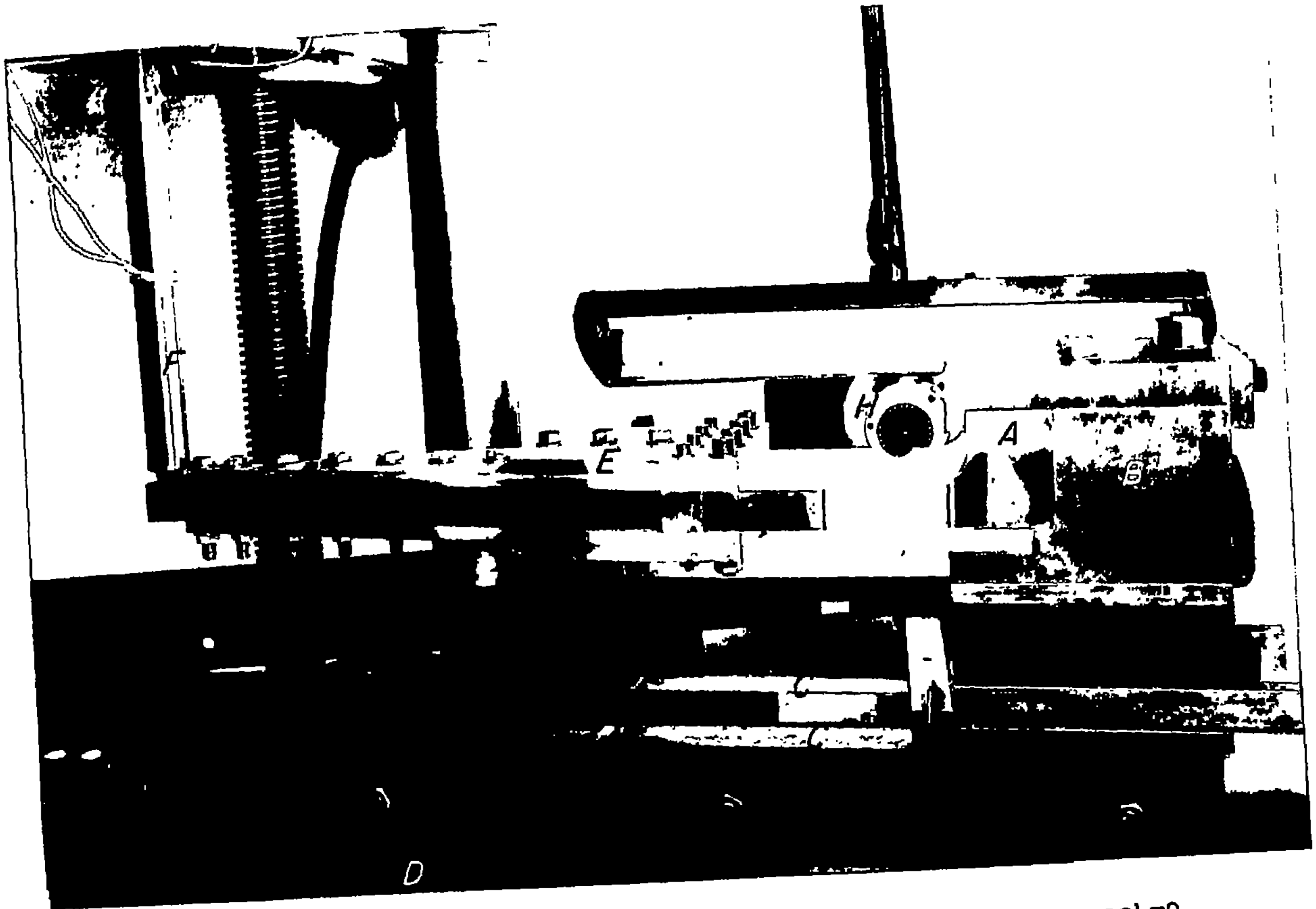


Figure 2.- Notched-bend-specimen profile.



L-92478

Figure 3.- Wide bend specimen ready for test.

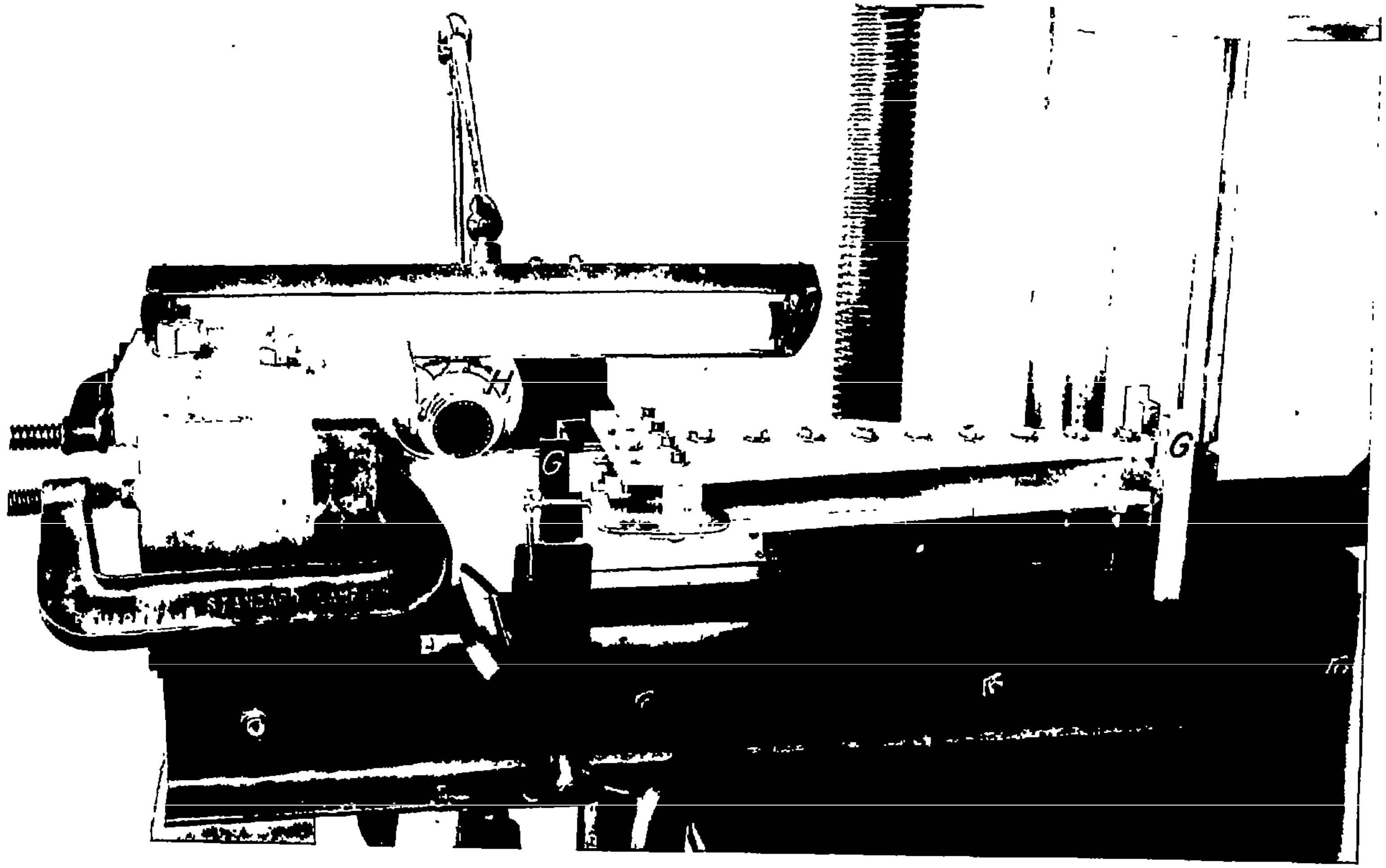
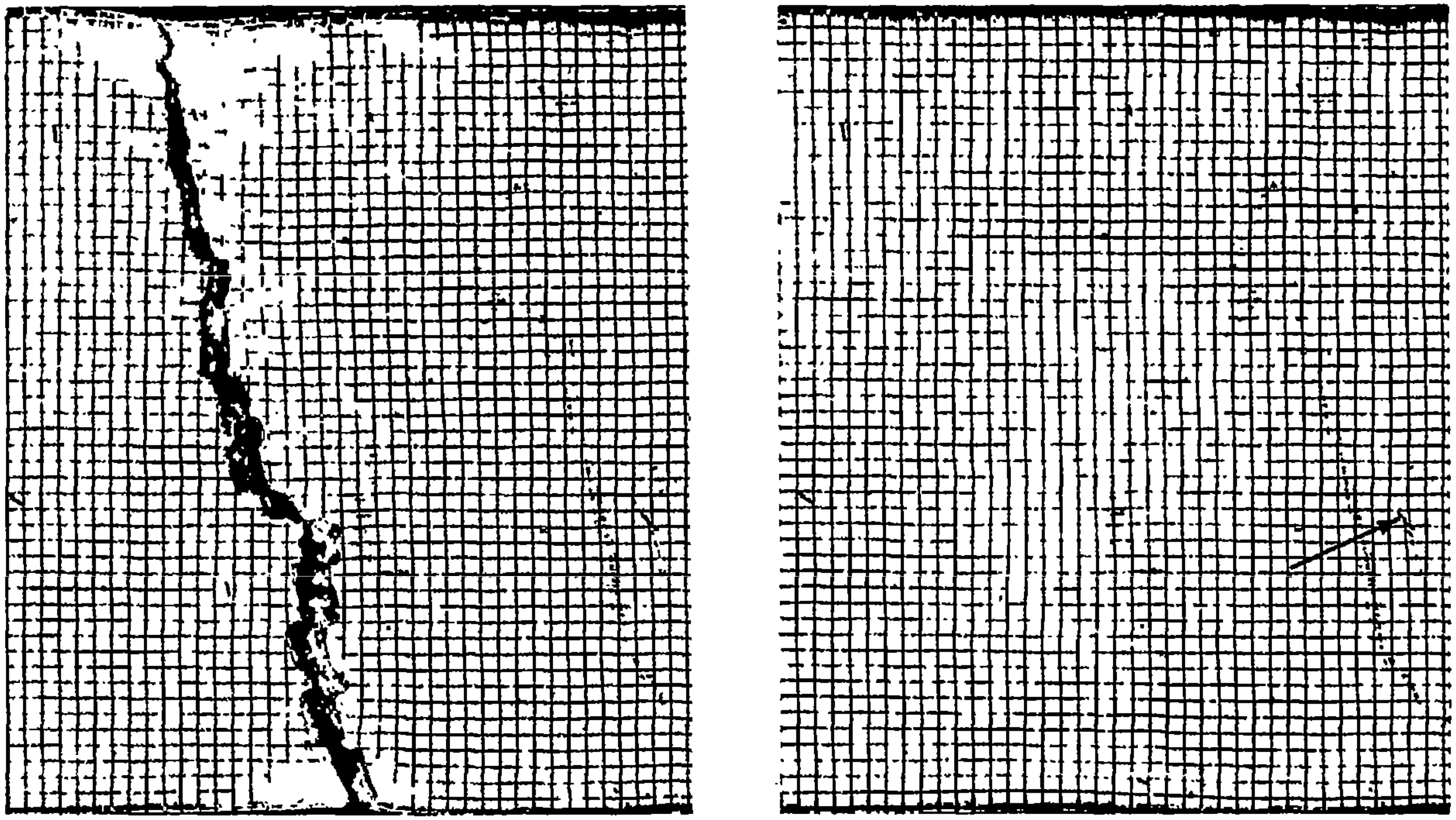


Figure 4.- Narrow bend specimen ready for test. L-92479

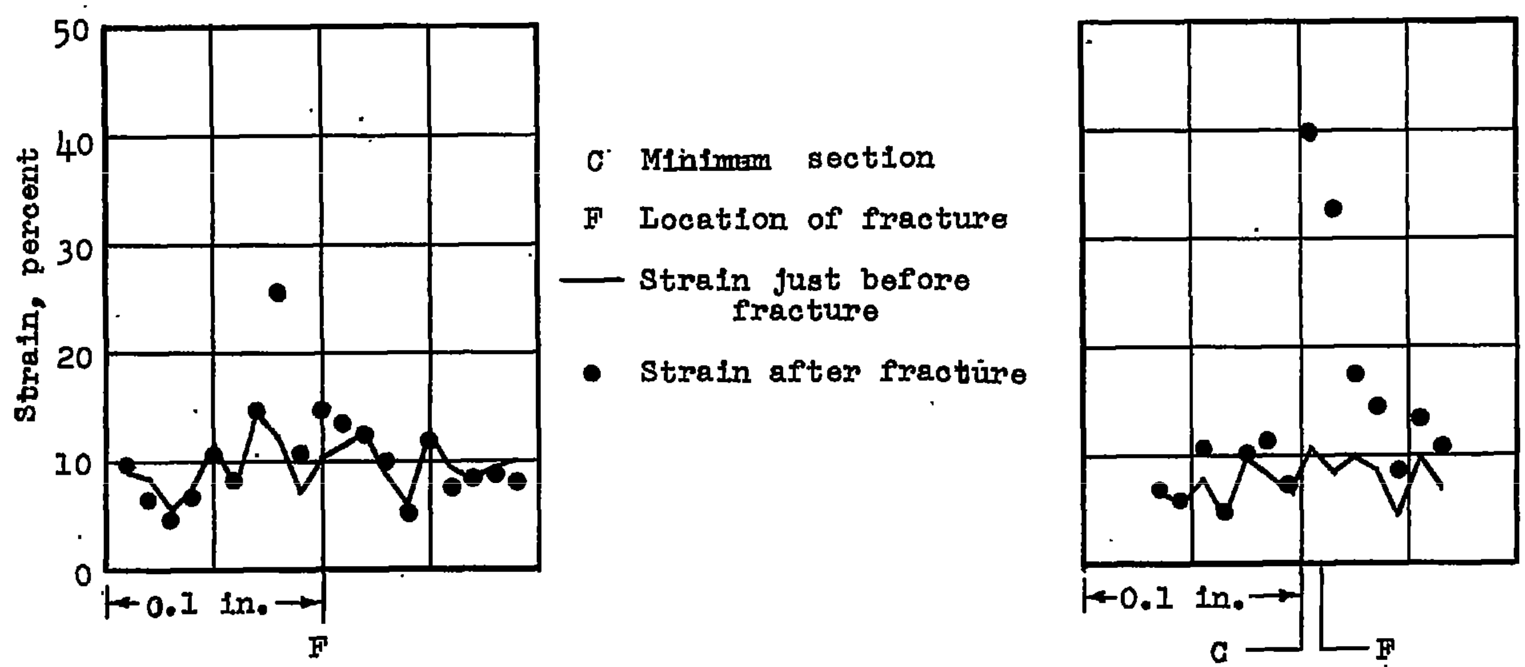


(a) After fracture.

(b) Before fracture.

L-92480

Figure 5.- Portion of specimen A5ZB4.



(a) Tensile specimen A3XM4.

(b) Bend specimen A3XM3.

Figure 6.- Strain in 0.01 inch in vicinity of fracture.

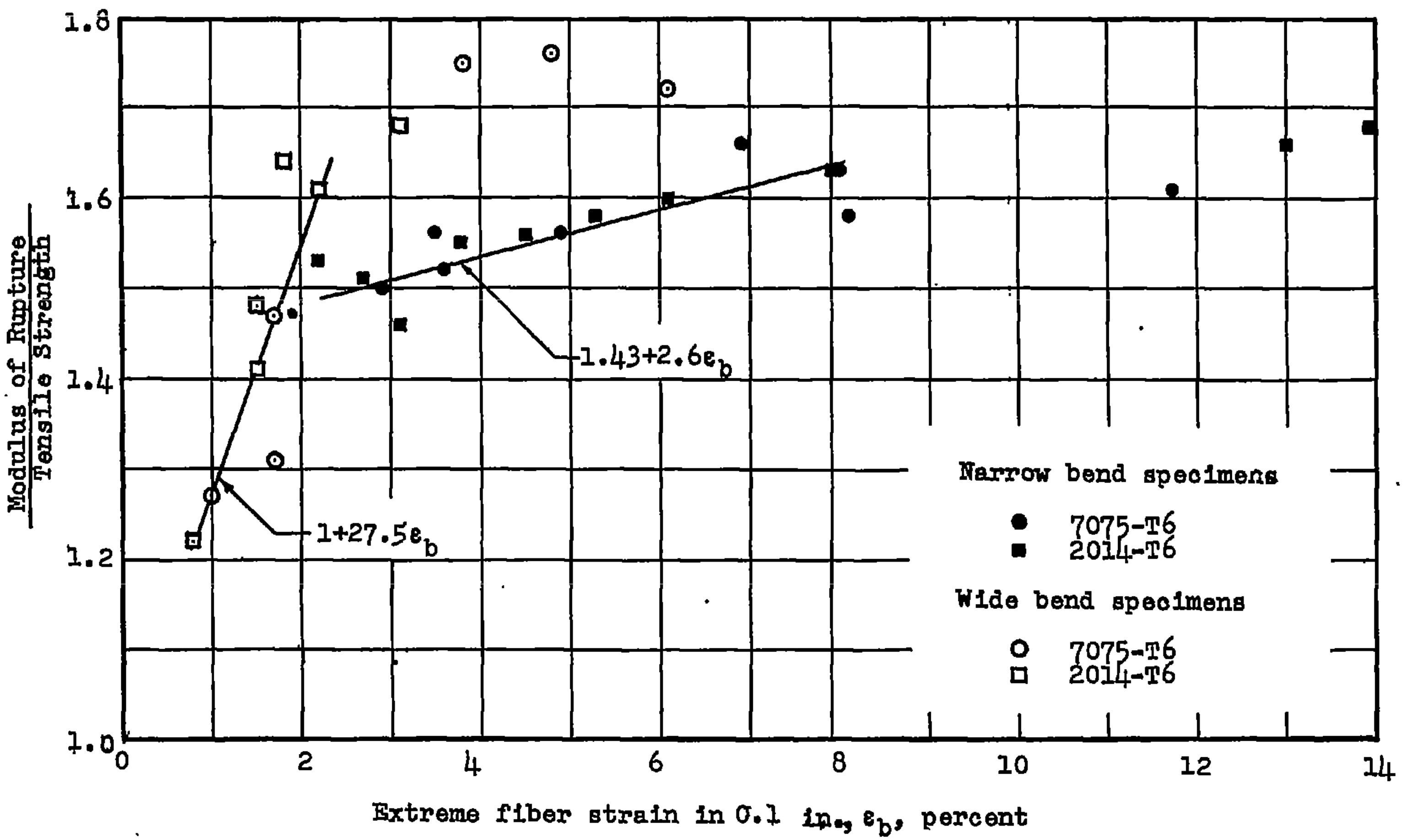


Figure 7.- Relation between extreme fiber strain in 0.1 inch just before fracture in bend specimens and ratio of modulus of rupture to average tensile strength of adjacent tensile specimens.

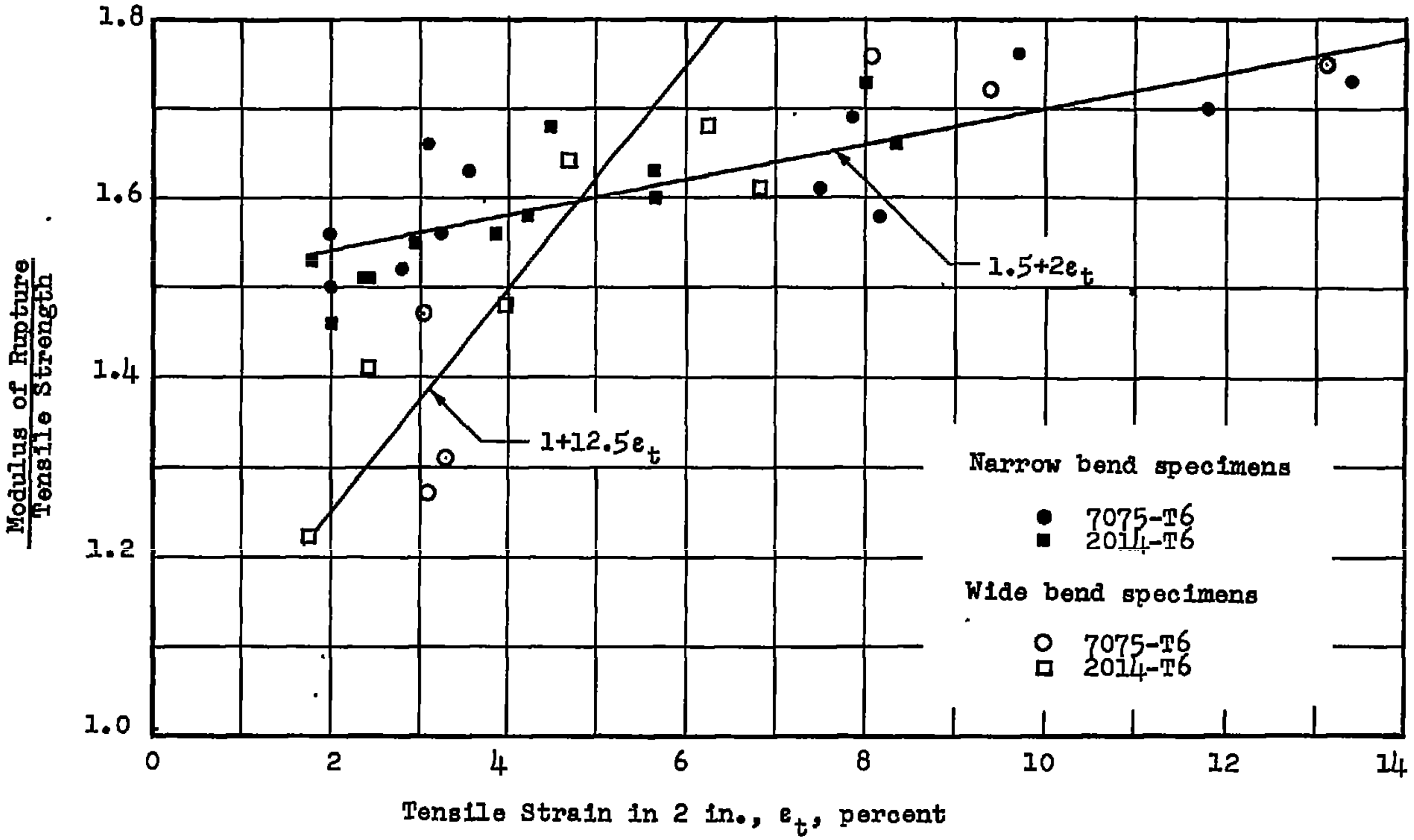


Figure 8.- Relation between average maximum strain in 2 inches in tensile specimens and ratio of modulus of rupture to average tensile strength of adjacent tensile specimens.

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